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ABSTRACT

This study presents evidence to substantiate the hypothesis that an important relationship exists between prior knowledge and resulting cognitive structure subsequent to instruction; and thus that relevant existing cognitive structure is an important variable affecting learning. The subjects were 126 first-grade students. Relevant existing cognitive structure was ascertained prior and subsequent to instruction using a modified Piagetian clinical interview. One pre- and three post-instructional interviews were administered. All the interviews were taped and transcribed. A conceptual propositional analysis was then employed to compare interviews. (Author/BB)

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Scientific Concept Learning in Children Subsequent to A-T Instruction: The Effect of Prior Knowledge On Resulting Cognitive Structure

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Abstract

Scientific Concept Learning in Children Subsequent to A-T Instruction: The Effect of Prior Knowledge on Resulting Cognitive Structure

This study was carried out within the general framework of Joseph D. Novak's A-TESP (Audio-Tutorial Elementary Science Project). The Project teaches scientific concepts to elementary school children and investigates the acquisition of these concepts by the children (Novak 1977; Pines 1977). The theoretical frameworks of the A-TESP are those propounded by David P. Ausubel (1968) and Mauritz Johnson, Jr. (1967, 1977).

Ausubel's focus is on concept and propositional learning. According to him, the most important single factor affecting meaningful learning is what the learner already knows. Consequently, teaching should be directed at the individual learner subsequent to ascertaining what s/he already knows.

The purpose of this investigation was to examine the effect of relevant existing prior knowledge on resulting cognitive structure, subsequent to planned science instruction. Cognitive structure was defined as the individual's conceptual organization of subject-matter.

Relevant existing cognitive structure was ascertained prior and subsequent to instruction using a modified Piagetian clinical interview (MPCI) (Pines 1978a). The subjects were 126 first grade children in the Ithaca City School District, New York. The instruction consisted of 24 Level I lessons. One pre- and three post-instructional interviews were administered.

All of the interviews were taped on audio-cassettes and transcribed verbatim. A conceptual propositional analysis (CPA) was then employed to compare interviews (Pines 1978a). The transcripts were transformed into propositional format and then relevant propositions (i.e. those related to the concepts under investigation) were separated from the irrelevant ones. The relevant propositions and episodes (groups of related propositions) from different interviews were then compared.

Clear evidence was found to substantiate the hypothesis that an important relationship exists between prior knowledge and resulting cognitive structure subsequent to instruction; and thus that relevant existing cognitive structure is an important variable affecting learning. The most compelling evidence for this claim was found in the divergence of initially different cognitive structures subsequent to an identical instructional sequence - instead of the otherwise expected convergence. Convergence was evident only at a very superficial or surface level.

The observed changes in cognitive structure were consistent with Ausubel's theory of meaningful learning. Relevant subsumers in cognitive structure facilitated the learning of new material, whereas misconceptions, if not adequately clarified, tended to inhibit learning (Pines 1978b).

The MPCI, together with a CPA, were found to be useful in assessing and comparing cognitive structures. Single propositions could be categorized, using different category systems; but the total interview of any single child displayed responses which fell into numerous categories no matter which system was used (Pines 1978c).

From a curricular and instructional point of view, the most important finding was that no single curriculum, or inflexible sequence of lessons, can be adequate for a variety of idiosyncratic cognitive structures in first grade students.

Some recommendations include investigation of the preschool environment, the future follow-up of the children investigated in this study, certain necessary revisions in the A-TESP, and the development of finer methodological tools for the collection and analysis of data.

Introduction

David P. Ausubel, in two important contributions to educational psychology (1963, 1968), provides the following epigraph:

> If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.
>
> (p. vi)

Few cognitive psychologists would argue with the potency of this insightful remark. It lies at the basis of individual differential cognitive psychology and it provides rationale and direction to the development of both curriculum and instruction. But what, if any, is the empirical evidence to support Ausubel's claim?

Most evidence for the effect of prior knowledge (or existing cognitive structure), viewed as the independent variable, on learning, taken as the dependent variable, is in the form of pre-post achievement test results. For example, King (1969) and Ring and Novak (1971) found a significant and almost perfect linear correlation between scores on a chemistry test administered prior to instruction and later achievement in the course. The relationship is striking; it is depicted in Figure 1.

Place Figure 1 approximately here.

What does such a relationship tell us? It actually says very little concerning the process of concept learning. As Novak (1977) has suggested, many questions remain unanswered:

> Donald Ring and I conducted a study that showed that achievement of college students in an introductory chemistry course appeared to bear a linear relationship to the knowledge of

> chemistry they had at the beginning of the course . . . Many questions remain to be answered: Was achievement proportional to 'entry' knowledge because the college course was poorly taught? Was the apparent linear relationship an artifact of the way in which achievement was measured in the college course? . . . Could students with little initial knowledge of chemistry have demonstrated high achievement if they had had more time to study? These and other questions remain . . .
>
> (p. 34)

In order to investigate the process of concept acquisition, another avenue of research was constructed. An Audio-Tutorial Elementary Science Project (A-TESP) was established by Joseph D. Novak, now at Cornell, with the intention of teaching science concepts to first and second grade children. Simultaneously the children's acquisition of these concepts could also be examined. This curriculum project proceeded in accordance with Ausubelian theory, i.e., it was established to differentiate a number of basic scientific concepts, within a curriculum and instructional framework proposed by Johnson (1967, 1977). The ways in which portions of this were constructed, implemented, and evaluated by graduate students can be found in a number of dissertations (e.g. McClelland 1970, Hibbard 1971, Nussbaum 1972). A detailed overview of the project and its development can be found in Postlethwait, Novak, and Murray (1972)* and in a dissertation by Pines (1977). The latter contains a list of all other relevant theses associated with the A-TESP and a clear description of the phases of development which are depicted below.

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* See Chapter VII by Joseph D. Novak.

Place Figure 2 here.

A list of the A-TESP lessons - Level I, intended for the first grade and used in this study - appears in Table 1.

Place Table 1 approximately here.

Examples of a typical lesson set-up are depicted in Figures 3 and 4.

Place Figures 3 and 4 approximately here.

Examples of typical lesson activities are captured in Figure 5.

Place Figure 5 approximately here.

Typically, in the past, research with the A-TESP has followed a procedure of constructing and implementing a lesson sequence and then evaluating whether, and how well, the concepts were learned. More recently, Rowell (1975, 1976), using the A-TESP as a vehicle for research, tried to evaluate a few of these lesson sequences. The actual technique of "cognitive mapping" used by Rowell to describe the concepts grasped by children remains quite obscure to this investigator. What is clear, however, is that children display a wide variability in their understanding, conceptual grasp, and explanations of natural phenomena.

The general research design, which typifies much of the previous A-TESP research and consists only of post-instructional evaluation, provides no clues to why children describe certain phenomena in certain ways. The crucial questions about the processes of concept acquisition are never asked in such a format. Even simple prerequisites, such as: What was learned by the child from the lessons and what was known to him/her prior to the lessons?, are rendered unanswerable with a limited post-instructional evaluation strategy.

In an effort to ameliorate some of the deficiencies in previous A-TESP research, and in order to gain insight into the process of concept acquisition, this study was attempted. The purpose of this investigation was, in effect, to empirically test Ausubel's theory. That is, the quest was to check the effect of prior knowledge on resulting cognitive structure. As we shall see, the methodology constructed and employed, enabled the researcher to gain insight into the process of concept acquisition. The research design was specifically planned to enable comparisons prior and subsequent to instruction. The A-TESP was used as the vehicle for research because it provides an ideal research instrument (see Pines 1977).

Methods

One hundred and twenty-six first grade children in six classrooms - distributed in three elementary schools in the Ithaca City School District - served as the sample for this study. Prior to the initiation of the A-TESP during the 1975-76 school year, a clinical interview was administered to each child in five of the six classrooms.* Then, subsequent to each "block" of lessons, a post-instructional interview was administered. The content of each "block" of lessons (dealing mainly but not exclusively with one major concept), along with the subsequent post-instructional interviews (Post IIs), is depicted in Tables 2a, 2b, and 2c.

Place Tables 2a, 2b, and 2 c about here.

* The technique of administering clinical interviews was perfected by the author and a co-worker in pilot studies prior to the 1975-76 school year. Thus, all of the interview content had been pre-tested and the interviewers were already proficient in administering clinical interviews.

Thus each child was interviewed four times: once prior to instruction (Pre II) and three times subsequent to instruction (Post IIs). Other measures of individual differences were also collected both prior and subsequent to instruction. The exact research schedule is depicted in Table 3.

Place Table 3 about here.

In the body of this paper, I will focus only on the analysis of interview data. These comparisons represent an effort to assess the effect of prior knowledge on subsequent concept learning. However, before turning to the description of the methods used to generate and analyze the interview data, it is worthwhile to highlight some additional findings. Significant correlations were found between numerous measures of individual differences. A few of these are depicted in Table 4.

Place Table 4 about here.

Notice, for instance, the significance between the Metropolitan Readiness Tests (Hildreth et al., 1969) administered prior to the first grade, and the Stanford Achievement Test (Madden et al., 1973) administered subsequent to the first grade. The correlation is .84 ($p \leq 0.001$), accounting for 71% of the variance! But what do such findings actually tell us? They are reminiscent of the numerous pre - post achievement test correlation studies mentioned previously (cf. Introduction, p. 1). Suffice it to say that they provide little or no insight into the processes of concept acquisition and learning.

Two methods were developed and refined for this study: 1) the Modified Piagetian Clinical Interview (MPCI), and 2) the Conceptual Propositional Analysis (CPA). Only a very brief outline of these methods can be reported

here; their elaboration is clearly beyond the scope of this paper!*

The MPCI format is depicted in Figure 6 and examples of the MPCI situation are depicted in Figures 7a and 7b.

Place Figure 6 about here.

Place Figures 7a and 7b about here.

Three exemplars used to initiate the interviews are depicted in Figures 8a, 8b, and 8c. A specific example of a task using another exemplar is captured in Figures 9a and 9b.**

Place Figures 8a, 8b, and 8c about here.

Place Figures 9a and 9b about here.

In order to facilitate the process of evaluation (viz. interviewing), a concept map was prepared. This concept map depicts the conceptual content of the A-TESP lessons. Such a concept map concerning the concepts of "life" and "energy" (i.e. the concepts on which this paper will focus) is displayed in Figure 10. A detailed description of the process of concept mapping and the use of concept maps is beyond the scope of this paper.

Place Figure 10 about here.

After the completion of an interview, which was captured and preserved in recorded format (i.e. on audio or video tape), the data was transformed into propositional form. This process which constitutes the first step in CPA is depicted in Table 5. Propositions were then sorted out and compared.*** To facilitate this process, all propositions were placed in order

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* In the future, while this paper is prepared for publication, the author will simultaneously complete a paper concerning these methods. However, at this time, information concerning the MPCI can be found in Pines (1977), Pines et al (1978), and Posner et al (1977).

** These 4 tasks were chosen for display because they will subsequently be used in this paper.

***Details concerning criteria for sorting out propositions are beyond the scope of this paper (cf. footnote *).

of appearance on large tagboard sheets, with the Pre II propositions opposite the Post II propositions as depicted in Table 6.

Place Table 5 about here.

Place Table 6 about here.

Subjects and the Structure of Presentation

Tapes were transcribed and then analyzed in an effort to detect changes in each child's cognitive structure over time and in order to compare different children. The results of this analysis proved too bulky for thorough documentation. Thus, only two complete case studies and three additional supportive studies, all dealing with the concepts of "life" and "energy", were finally reported. Of the numerous tables and figures which were composed concerning this research effort (see Pines 1977), only a small percentage can be displayed here.

These two case studies were chosen because they illustrate most of the points found in the rest of the sample. Furthermore, these two children were complementary in that each displayed a unique cognitive structure and different misconceptions prior to instruction. Finally, the two children were matched so as to minimize the difference on other variables: they were the same sex, the same age, from the same classroom, etc. A comparison of these two children appears in Table 7.

Place Table 7 about here.

In the following section some Pre - Post II excerpts concerning the concepts of "life" and "energy" are provided. These Pre - Post II comparison segments were chosen to exemplify quantitative and qualitative changes in cognitive structure prior and subsequent to the A-TESP isntruction. By comparing the two complementary case studies, it is possible to depict the

effect of prior knowledge on the subsequent acquisition of the concepts taught. One example of lesson content will be necessary to show the differential effect of the same content on the two complementary cognitive structures.

A discussion of the findings, interpretations, and conclusions will be reserved for the final section of the paper.

Data and Results

Table 8 presents a comparison of Pre - Post II data taken from Case Study 1.

Place Table 8 about here.

A number of facts should be noticed. First of all, the child in the Pre II, understands that seeds are alive! However, her criteria for judging whether something is or is not alive are inadequate (viz. "squeezeability"). In the Post II, the child provides a sophisticated probabilistic explanation concerning her decision as to whether seeds are to be considered alive or not. Her criteria have most obviously shifted from "squeezeability" to "growth". I will later attempt to show that the sophistication achieved in this response is contingent upon both the child's prior knowledge (i.e. that seeds are alive) and upon the lesson content.

The above can now be contrasted with the child in Case Study 2. whose response concerning the same interview content appears in Table 9.

Place Table 9 about here.

This child, in the Pre II, considers seeds to be dead! She does, however, understand that seeds can grow, and thus, there is a distinct misconception concerning the "continuity of life". This misconception is most clearly carried into and elaborated upon in the Post II. This child's cri-

terion of "movement" for the concept of "life" becomes reinforced and elaborated in the Post II as depicted in Table 10.

Place Table 10 about here.

In order to establish the reasons behind these different responses of the two children and more specifically, to understand why the misconception in Case Study 2 was perpetuated, the relevant lesson content dealing with these issues was carefully examined. Table 11 provides two examples of the lesson content from the A-TESP lessons #13 and #14.

Place Table 11 approximately here.

Indeed, it now becomes possible to grasp the differential understanding of the two children. The child who came with a prior knowledge of seeds as being alive, was able to incorporate the lesson content into her cognitive structure and this resulted in the sophisticated response noted previously in Table 8 (cf. p.). On the other hand, the child who came to the lessons with the prior knowledge of seeds being dead, was led to believe by the lessons (and justifiably so!) that seeds come to life when provided with adequate prerequisites.

Clearly there is a problem with the lesson content. The lessons do not succeed in uprooting or changing existing misconceptions; in fact, they perpetuate and differentiate these misconceptions. The root of the problem lies in the failure to introduce the concept of "dormancy" to explain the fact that seeds can be alive but in a quiescent state.

The relationship between Pre and Post II data is evident! Furthermore, such threads are evident in all the other interview data. Tables 12 and 13 provide examples of the perpetuation of the same misconception in Case Studies 4 and 5.

Place Table 12 about here.

Place Table 13 about here.

In the data taken from the control class who received no Pre IIs, we can almost positively determine whether the child came to the lessons with a misconception concerning "life" or not. That is, this author believes that we can accurately guess what the child's responses in the Pre II would have been based on Post II data. This point is exemplified in Table 14 taken from Case Study 3.

Place Table 14 about here.

Another comparison between the two major case studies will now be made using the concept of "energy". In Table 15, the child in Case Study 1 uses the concepts of "electricity" and "energy" to explain certain phenemona.

Place Table 15 approximately here.

At least two things should be mentioned here: First of all, the child has a misconception concerning the "conservation of energy"; and secondly, the child has a profound misconception concerning the "nature of energy". The child believes that electricity is made in the same way that people make fire, for example. And the child fails to recognize fire as a type or transformation of energy. Both of these misconceptions are clearly carried into the Post II. A closer look at the child's conception of "energy" reveals a clear elaboration of misconceptions from the Pre to the Post II as depicted in Tables 16 and 17.

Place Table 16 about here.

Place Table 17 about here.

In Table 16, the failure to understand the sun as a source of energy in the Pre II results later in an inadequate understanding of energy transformations in a "food chain" with the sun as initiator. Again in Table 17, the thread from Pre II to Post II is clearly seen in the child's misconception concerning "fire".*

Table 18 depicts a Pre - Post II comparison concerning the same content for Case Study 2. The responses in the Pre and Post IIs are both conceptual. However, a change can be noticed in that the concept of "energy", introduced by the lessons, later subsumes the concept of "electricity". The child has learned something.

Place Table 18 about here.

This is even more noticeably depicted in Table 19 where in the Pre II, the child is groping for a concept to relate "electricity" to "fire". She eventually uses the low-level concrete function of "cooking". But in the Post II, once the concept of "energy" has been acquired and differentiated, it can be used to explain previously isolated concepts.

Place Table 19 about here.

Notice that the two case studies are indeed complementary. The first child has a well-differentiated concept of "life" but a poorly differentiated concept of "energy", riddled with misconceptions. And the second child has a poor concept of "life" (particularly concerning the "continuity of life") but a well-differentiated concept of "energy". The fact that there is a clear relationship between Pre and Post IIs is, to date, the most substantial evidence known to this author in support of Ausubel's theory. I will elabo-

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* Notice the interesting animistic explanation in proposition #60. This should be contrasted with the child's other conceptual and mechanistic explanations. We find a host of different types of explanations in all children, depending on the content under discussion and the child's conceptual grasp of that content. Thus, it would seem absurd to categorize children as "animistic", "mechanistic", etc., in toto (Pines 1977).

rate on the details of the results in the next and final section of the paper.

Conclusions, Interpretations, and Some Implications

The major conclusion of this study is that prior knowledge does have a profound influence on learning. Relevant subsumers in cognitive structure facilitate learning; misconceptions, if not adequately and specifically addressed in instruction (so as to rectify individual, idiosyncratic misconceptions) persist and both inhibit and misdirect future learning. Clear evidence can be seen, then, to substantiate the hypothesis that an important relationship exists between prior knowledge and resulting cognitive structure subsequent to instruction. This finding is in accordance with, and could be predicted by, Ausubel's theory of learning.

Only in the framework of the Ausubelian theory, in fact, does all of the otherwise unrelated data collected in this study make sense. We can see beyond doubt that children are capable of *learning* scientific concepts, and then applying these concepts to explain phenomena. However, we must be careful when using the word "learning". For concepts are not acquired instantaneously in an "all or none" fashion, but rather, they are *progressively differentiated* (See Pines 1977 and Ausubel 1968). Both concepts and misconceptions can be differentiated in cognitive structure and the latter need to be ameliorated for the former to appro-

priately proceed.* Ausubel's conceptual framework and terminology enable one to describe and investigate such concept learning.

The design of this study (i.e. the pre-post evaluations) and the methods employed to generate and then analyze data (i.e. MPCI and CPA) enabled a more precise specification of the effect of prior knowledge than most other studies afford. The latter generally employ either achievement tests or associative measures which fail to evaluate at different points in time with some controlled intervening instruction. Vital to this study was the fact that single propositions could be sorted out and compared.** Generally, the most compelling evidence to substantiate the claim that existing cognitive structure is an important variable influencing learning, lies in the divergence of initially different cognitive structures subsequent to an identical instructional sequence. This phenomenon of "cognitive divergence" albeit identical A-T instruction is precisely in accordance with Ausubel's (1968) theory.

> ...it is precisely this interaction of new learning tasks with existing knowledge in the learner that is the distinctive feature of meaningful learning.
>
> (p. 20)

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* The fact that misconceptions can be meaningfully learned (i.e. progressively differentiated in cognitive structure) will be the subject of a separate paper (Pines 1978b).

** Although single propositions could be categorized using a host of different systems, the total interviews of any child displayed responses that fell into numerous categories no matter which category system was used. In short, no child could be categorized in toto (See Pines 1977 and Pines 1978c). The fact that children are capable of learning scientific concepts, and the difficulties inherent in trying to subsequently categorize the children, have already been pointed out more than three decades ago (See Oakes 1947).

Ausubel goes on throughout his text to elaborate upon the mechanisms of meaningful learning. Without such a theoretical framework, the phenomenon of "cognitive divergence" subsequent to identical instructional input would seem an anomaly to the naive observer. That is, one might quite reasonably expect that with identical instructional input (of the sort provided by A-T instruction), initial differences in cognitive structures would disappear. Thus convergence would occur with the final products of cognitive structure resembling the structure of knowledge contained in the instruction. In fact, this is the assumption contained in all non-individualized instructional packages and is no doubt an implicit belief of most teachers. Convergence and divergence of cognitive structures appear in Figure 11.

Place Figure 11 about here.

In a, we see a situation of "cognitive convergence", expected either when existing cognitive structure plays no role in learning (e.g. when the mind is considered a "blank slate" which absorbs information); or when instruction is individualized and successful in clarifying idiosyncratic existing misconceptions. In b, we see what happens in reality when initially different cognitive structures receive an identical A-T instructional input (which fails to take into account and rectify existing misconceptions) as was empirically confirmed in this investigation.*

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* Two divergent cognitive structures can often quite easily be brought to converge with the use of one or two good instructional examplars. If this was not the case, we would be forced to the false conclusion that cognitive structures must inevitably diverge and that the divergence is irreconciliable. In fact, good teaching should capitalize

Such "cognitive divergence" is marked when instruction fails to address specific misconceptions. Finally, in c, it is hypothesized that over a long period of time, two cognitive structures will ultimately converge with the structure of knowledge as learners become experts in a certain content domain. Nevertheless, a micro-analysis might show fluctuations pointing to misconceptions and their reconciliation.

Concept learning was observed to occur, in this study, in several modes. Sometimes, concept learning involved a distinct change in the meaning of a concept in cognitive structure which could be traced. Two prototype modes of conceptual change in cognitive structure synthesized from the data presented in this paper, appear in Figures 12 and 13.

Place Figure 12 approximately here.

Place Figure 13 approximately here.

In the first case, a clear shift in criterial attributes is evident; whereas in the second case, a change in the extension of the concept is clear. Although an analysis of the concept of "concept" is beyond the scope of this paper, the reader should acknowledge the fact that conceptual change in cognitive structure (viz. the ideosyncratic change in the meaning of a concept) always involves a simultaneous change in both the intension and extension of a concept (See Pines 1977). Most commonly when we observe changes in cognitive structure, the latter is most recognizable. However, the teacher, in attempting to supply the students

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on providing for "cognitive dissonance" (See Festinger 1957). This is done in an effort to bring about integrative reconciliation, the rectification of misconceptions, and the ultimate convergence of cognitive structure with the structure of knowledge.

with concepts, can approach the teaching task by either providing definitions for the meaning of a concept (viz. extracting and emphasizing the intension) or providing good exemplars (viz. trying to delineate the extension). Obviously both modes of instruction should be emphasized simultaneously.

Numerous other findings, including recommendations for future research, have resulted from the research effort reported in this paper. However, the elaboration of these findings and recommendations is too bulky to include here. Thus, these additional conclusions are summarized in the following brief statemens with the intent of elaborating upon them in future publications.*

1. Children can learn (or more accurately, differentiate) and apply scientific concepts to explain natural phenomena subsequent to an appropriately planned instructional intervention.
2. Concepts are not finalistic entities, which can be decisively learned instantly. Rather, concepts are flexible insofar as they do not have clear-cut boundaries or specifiable criterial attributes. The "flexibility" of concepts enable conceptual change over a long period of time, on the one hand, and enable the learning of concepts (which may be a slow and tedious process of cognitive differentiation) on the other. Although a concept sufficient for communication can be acquired from even one prototype exemplar, the concepts so acquired continue to undergo differentiation.

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* The major conclusions of this paper which the author wishes to emphasize are underlined.

3. The clinical interview is a viable way for ascertaining children's relevant existing cognitive structures concerning specific scientific concepts. The discourse generated by the child is an indicator of the child's cognitive structure.*

4. Valid clinical interview data can be broken down into propositions which are combinations of concepts specifying relationships and have some truth value. The content of such propositions can be evaluated as indicators of cognitive structure (and conceptual differentiation). Misconceptions can also be pinpointed.

5. Conceptual propositional analysis (CPA) is a convenient way of comparing the cognitive structures of different children or of a specific child at two or more different times (with or without interveining instruction).

   a. CPA captures existing conceptual relationships in the idiosyncratic belief systems and can enable the identification of changes from pre to post instruction.

6. Each child exhibits a host of different responses highly dependent on his/her knowledge of the subject-matter under investigation. Thus, although different responses can be categorized according to physical causality (or other such systems) no child can be categorized in toto as belonging to any single category or stage.

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* Obviously the validity of the interview data is contingent on the validity of the interview. In order to achieve a valid clinical interview much experience and a thorough knowledge of the subject-matter are a *sine qua non*.

7. Prior knowledge (or existing relevant cognitive structure) is an important variable affecting resulting cognitive structure. A clear relationship can be seen between what the child knew prior to instruction and what s/he knows subsequent to instruction, viz. learning of scientific concepts is subject-matter specific.
8. No single inflexible sequence of lessons is adequate for the instruction of children with different existing cognitive structures.
9. Relevant subsumers can facilitate learning while misconceptions can impede learning. Thus curriculum development and instructional planning must take into account the students' existing cognitive structures.
   a. Misconceptions must either be mitigated (and if possible eradicated) or utilized to the student's advantage (i.e. reconciled).
   b. Concrete exemplars to be used as instrumental content in instruction, should be developed in consideration of the student's prior knowledge and experiences.
10. Ausubel's theory of learning explains the acquisition and retention of concepts and can serve as a guide to curriculum and instruction.
11. An important step for future research is the development of an adequate methodology which will enable a sophisticated quantitative analysis of interview data which does not lose the meaning inherent in the raw data (in the process of reduction).

Alternately, with older students, other methods of evaluation can be used in combination with the clinical interview, and their convergence with interview data can serve to estimate method validity.

12. Important future directions for the A-TESP are:
    a. Evaluating the children's backgrounds prior to formal schooling.
    b. Following through the children who have been instructed with the A-TESP in order to ascertain long-term effects.
    c. Attempts to supplement the A-T instruction as planned with appropriate teacher intervention, additional A-TESP experiences properly implemented, and on the whole, an integration of the science content into overall classroom activities.
    d. Close and frequent monitoring of the children's activities in the A-TESP carrels during lesson operation (See Mormann 1978).
13. The results of this research clearly indicate specific portions of instruction which need to be revamped. Content analysis of the lessons combined with research data should enable the amelioration of existing deficiencies.

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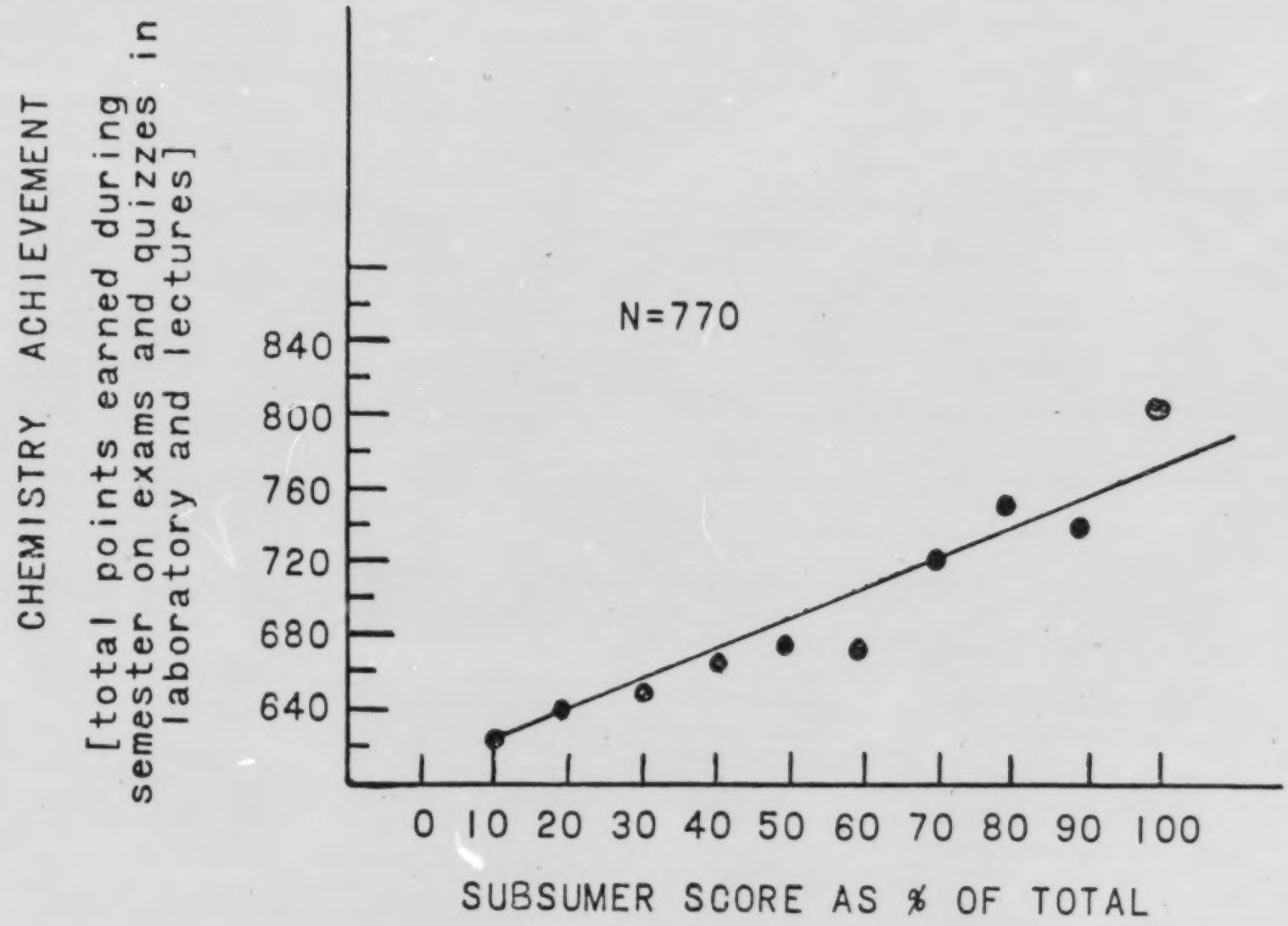


Figure 1. Correlation Between Scores on Pre- and Post-Instruction Chemistry Tests

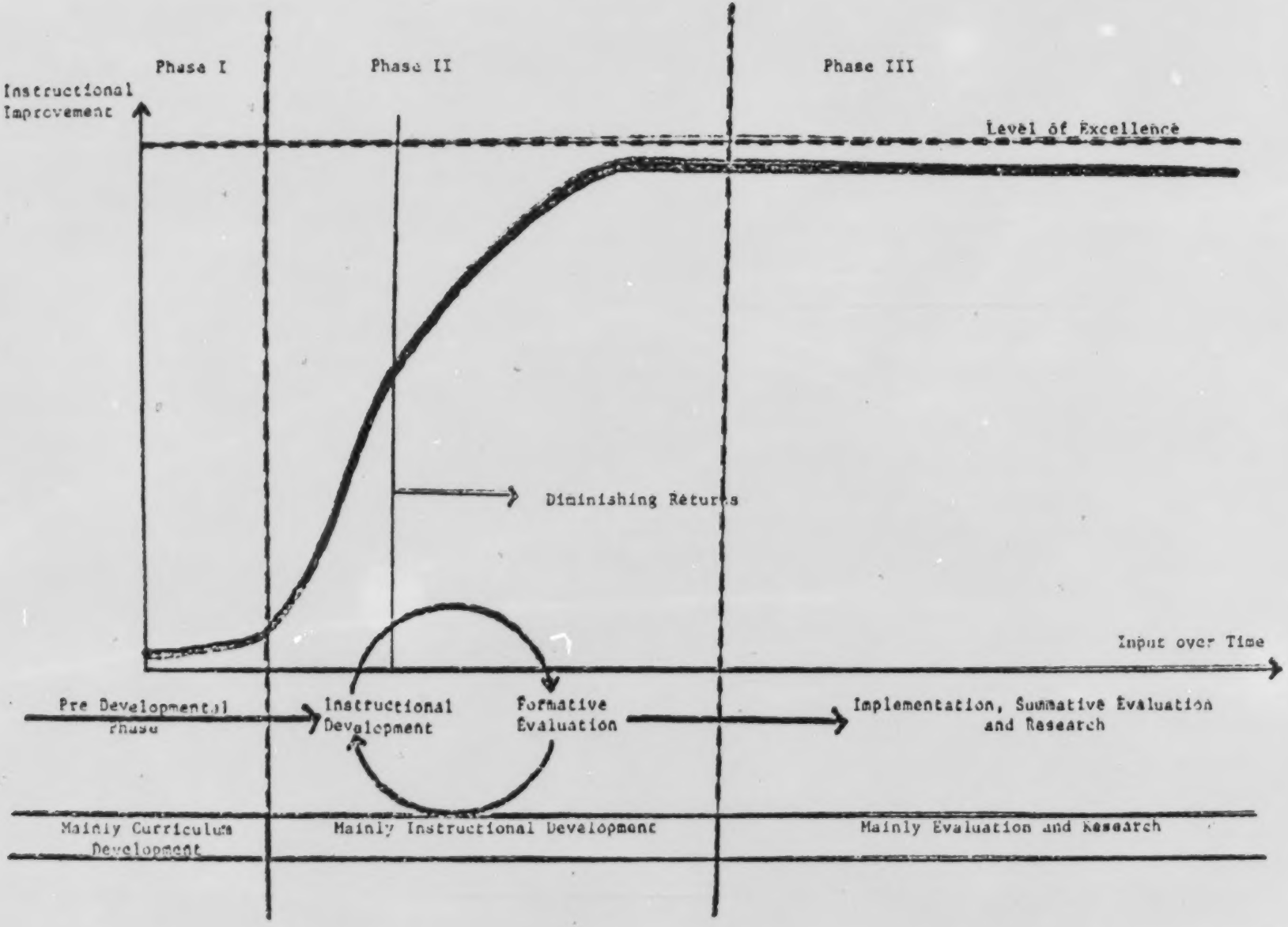


Figure 2. Phases of the A-TESP

28

Table 1. List of A-TESP Level I lessons

Level 1 Lesson Number	Lesson Title
1	Classification of Objects By Their Size, Shape and Weight
2	Classification of Batteries: Some Batteries Can Make Bulbs Light and Others Cannot
3	Batteries Are a Source of Electric Energy: Electric Energy Can Cause A Bulb To Change
4	Electric Energy Is Involved In Many Kinds Of Changes
5	Whenever You Notice A Change You Know That Energy Is Involved
6	Differing Amounts Of Change Occur When More Energy Or Less Energy Is Involved
7	Energy Can Be Stored and Involved In Future Changes
8	People Use Energy and Change Themselves and Other Things
	I N T E R V I E W O N E
9	There Are Some Ways In Which All Animals Are Alike
10	Moving and Growing Are Changes: All Animals Use Energy From Food To Change
11	Different Animals Eat Different Kinds Of Food
12	Growing Plants Need Air, Water and Light
13	Living Seeds Change In Certain Ways
14	Growing Is A Kind Of Change In Plants And Animals
15	A Comparison Of Plants And Animals
16	Nothing Changes By Itself
	I N T E R V I E W T W O
17	Air Is Real; Air Causes Changes
18	Some Distinctive Features Of Solid Things, Liquid Things, And Air
19	Things Are Made Of Parts
20	All Solid Things Can Be Thought Of As Being Made Of Little Parts. These Little Parts Can Be Called Molecules
21	All Liquid Things and Air Can Also Be Thought Of As Being Made Of Little Parts Called Molecules
22	Wind And Smells Demonstrate The Movement Of The Molecules Of Air
23	Air Molecules Are Comtantly Moving Around
24	The Molecules Of A Solid Do Not Move Around Freely, While The Molecules Of A Liquid Move More Freely, And The Molecules Of Air Move Most Freely
	I N T E R V I E W T H R E E

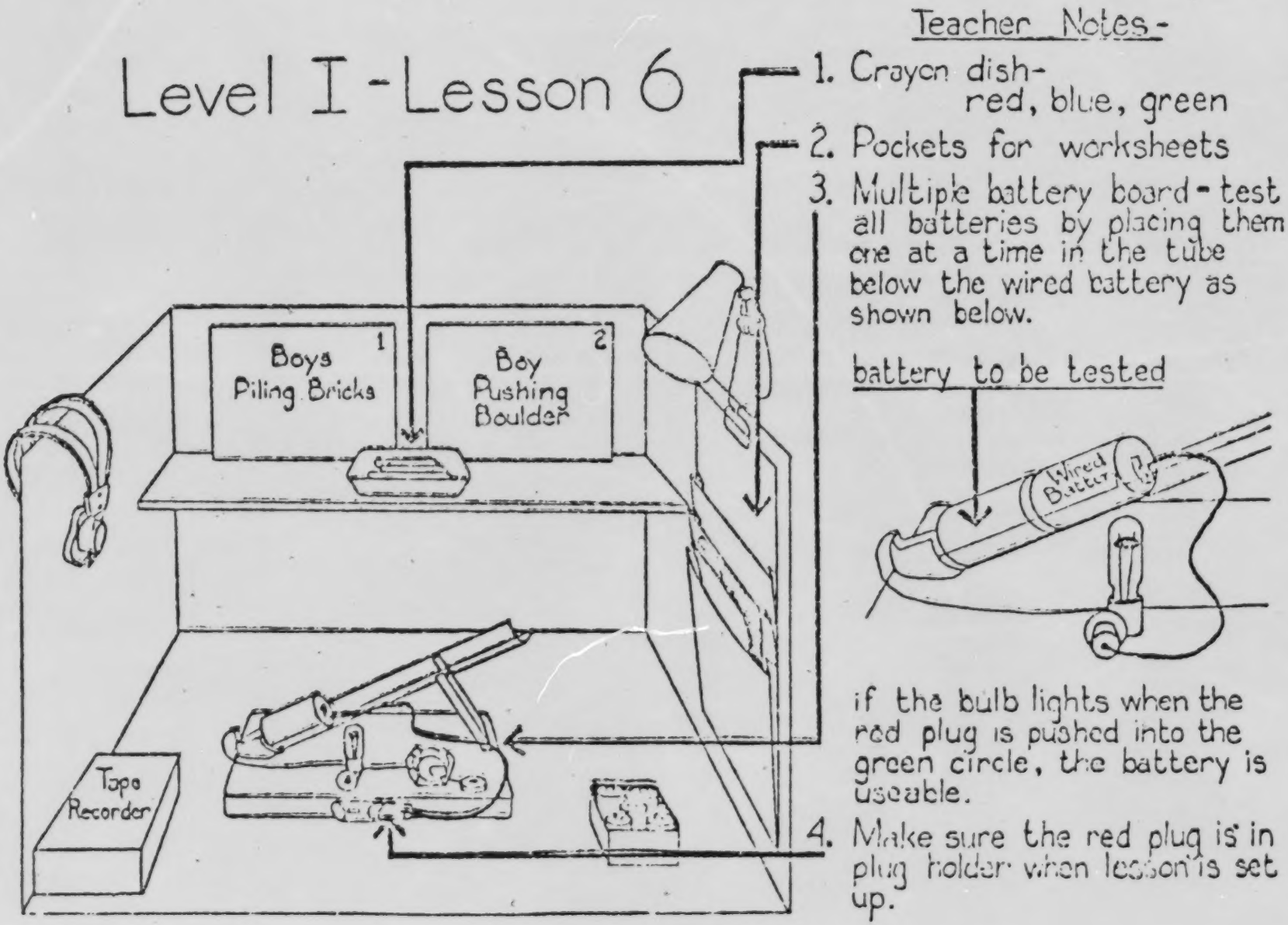

Level I - Lesson 6
Teacher Notes -
1. Crayon dish- red, blue, green
2. Pockets for worksheets
3. Multiple battery board - test all batteries by placing them one at a time in the tube below the wired battery as shown below.
battery to be tested
Wired Battery
if the bulb lights when the red plug is pushed into the green circle, the battery is useable.
4. Make sure the red plug is in plug holder when lesson is set up.
Boys Piling Bricks
1
Boy Pushing Boulder
2
Tape Recorder

Figure 3. Example of a Set-Up Picture

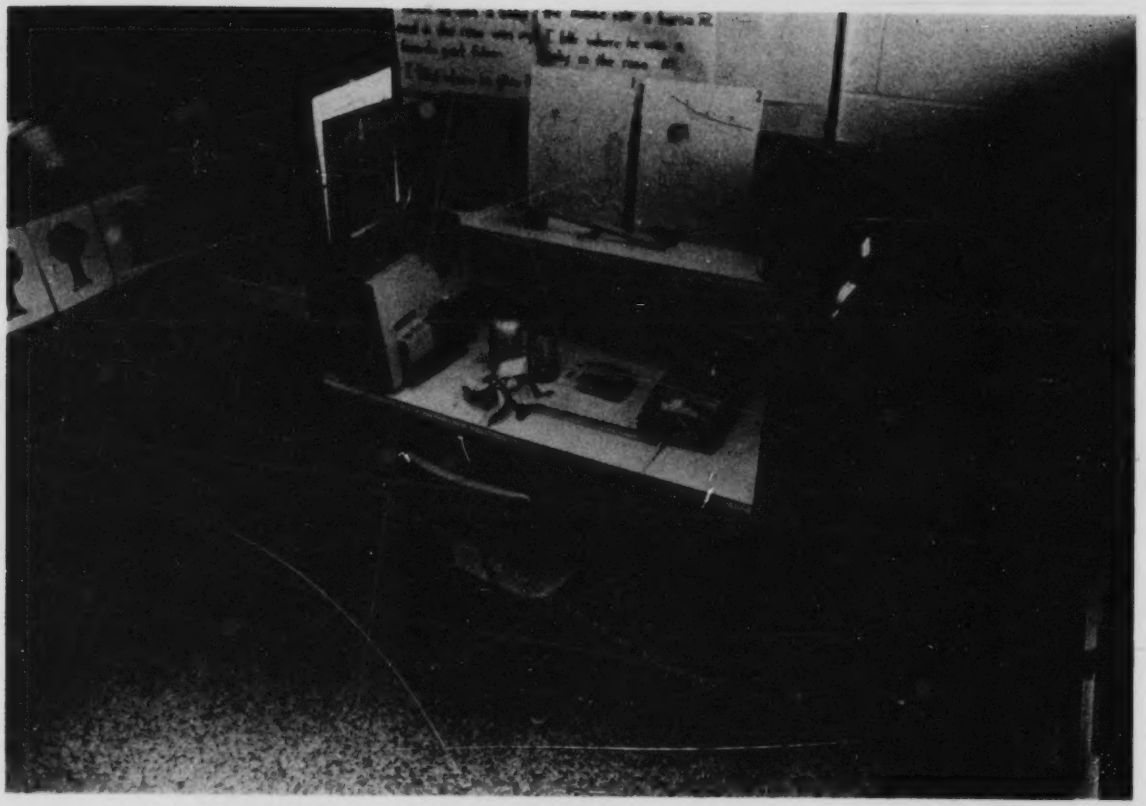


Figure 4. Photo of a Typical Lesson Set-Up.

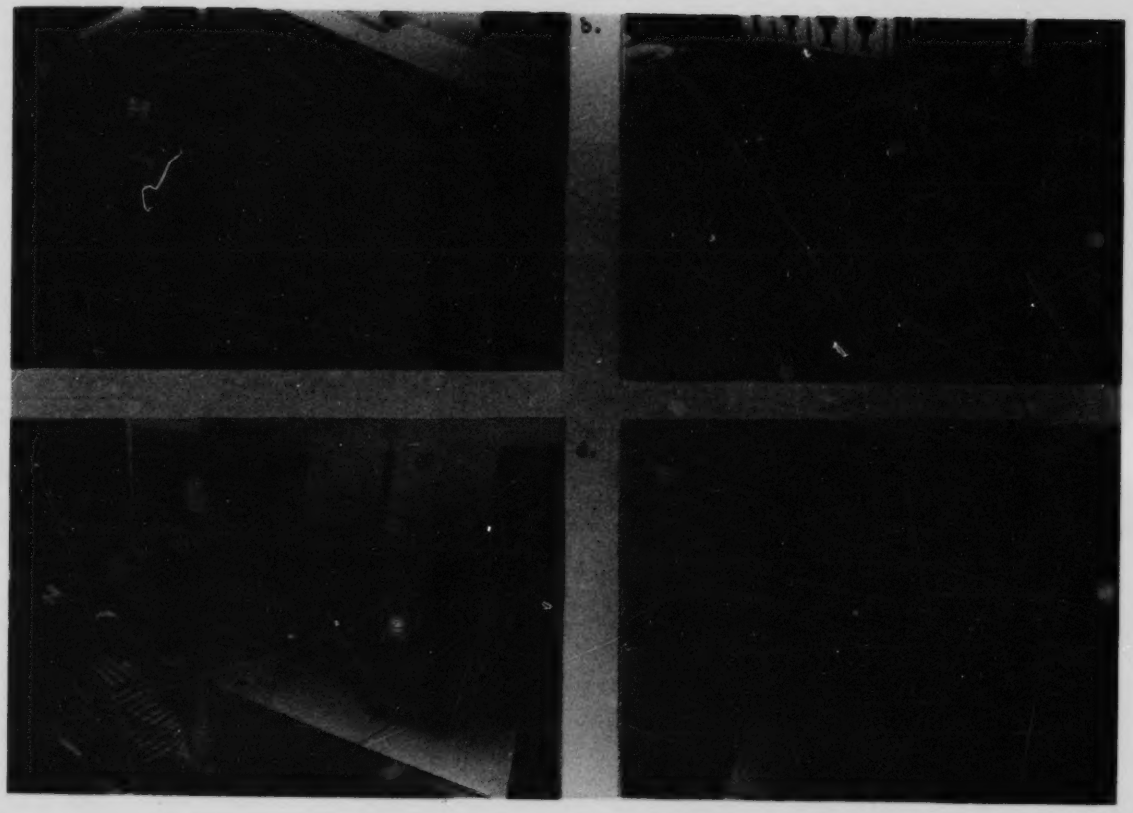


Figure 5. Examples of Typical Lesson Activities.

Table 2a. A-TESP Level I Lessons, First "Block".

Level 1 Lesson Number	Lesson Title
1	Classification of Objects By Their Size, Shape and Weight
2	Classification of Batteries: Some Batteries Can Make Bulbs Light and Others Cannot
3	Batteries Are a Source of Electric Energy: Electric Energy Can Cause A Bulb To Change
4	Electric Energy Is Involved In Many Kinds Of Changes
5	Whenever You Notice A Change You Know That Energy Is Involved
6	Differing Amounts Of Change Occur When More Energy Or Less Energy Is Involved
7	Energy Can Be Stored and Involved In Future Changes
8	People Use Energy and Change Themselves and Other Things
	I N T E R V I E W O N E

35

Table 2b. A-TESP Level I Lessons, Second "Block".

9	There Are Some Ways In Which All Animals Are Alike
10	Moving And Growing Are Changes: All Animals Use Energy From Food To Change
11	Different Animals Eat Different Kinds Of Food
12	Growing Plants Need Air, Water and Light
13	Living Seeds Change In Certain Ways
14	Growing Is A Kind Of Change In Plants And Animals
15	A Comparison Of Plants And Animals
16	Nothing Changes By Itself
	I N T E R V I E W T W O

Table 2c. A-TESP Level I Lessons, Third "Block".

17	Air Is Real; Air Causes Changes
18	Some Distinctive Features Of Solid Things, Liquid Things, And Air
19	Things Are Made Of Parts
20	All Solid Things Can Be Thought Of As Being Made Of Little Parts. These Little Parts Can Be Called Molecules
21	All Liquid Things and Air Can Also Be Thought Of As Being Made Of Little Parts Called Molecules
22	Wind And Smells Demonstrate The Movement Of The Molecules Of Air
23	Air Molecules Are Constantly Moving Around
24	The Molecules Of A Solid Do Not Move Around Freely, While The Molecules Of A Liquid Move More Freely, And The Molecules Of Air Move Most Freely

I N T E R V I E W T H R E E

Table 3. Research Schedule of This Study.

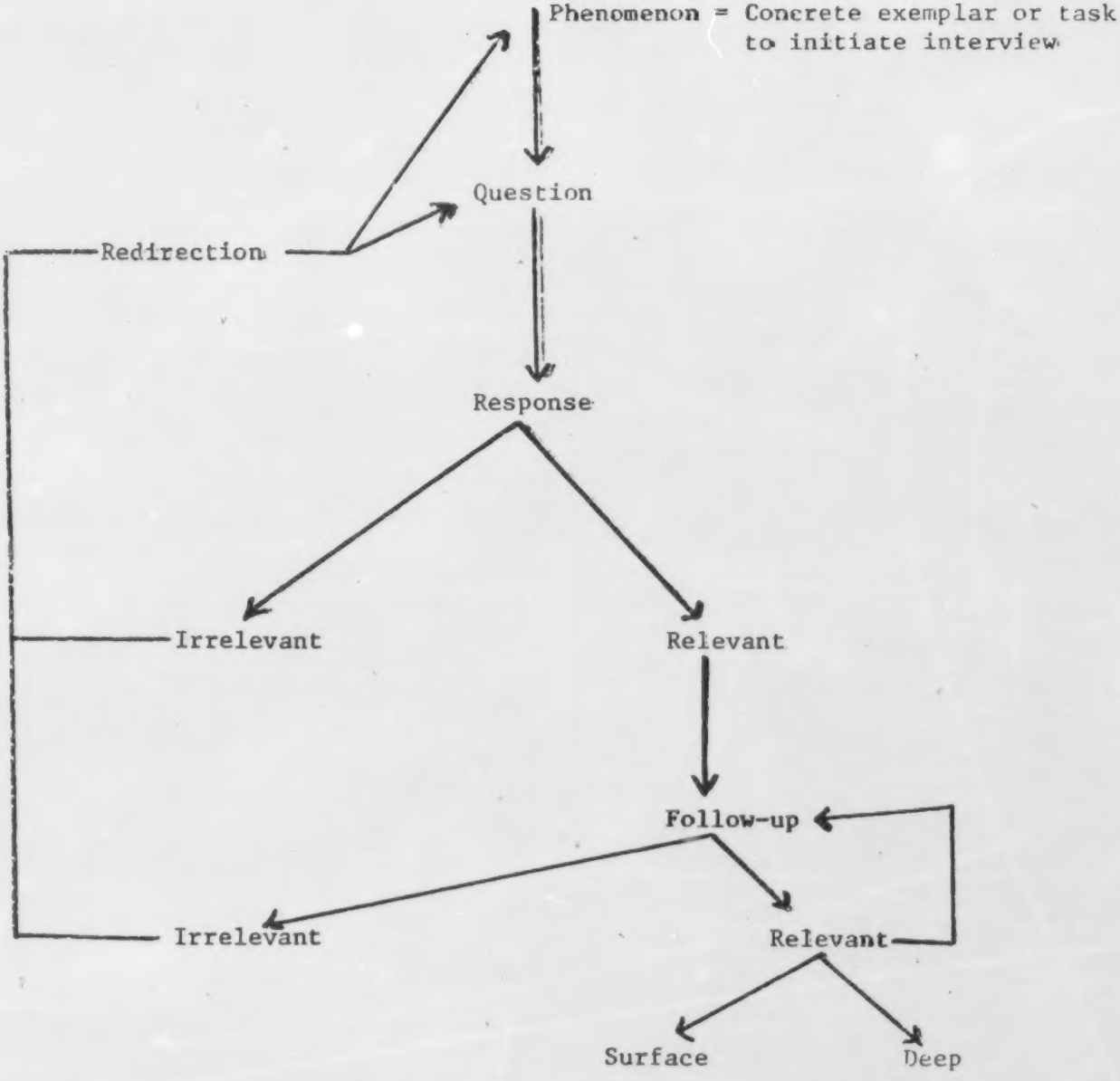
A-TESP Administration and Evaluation During the 1975-76 Interim.

Time		
Spring 1975	Pilot Studies	Metropolitan Readiness Tests - Administered at the end of the kindegarten year. Construction of clinical interviews.
Summer 1975		Preparation of the A-TESP Level I lessons for the 1975 - 76 school year. Meetings with representatives of the Ithaca School District. Meeting with all of the elementary school principals. Individual meetings with participating teachers.
Fall 1975	Lessons 1 - 8	Pre-instructional evaluation1 1) Pre-Instructional Interviews in five classes. 2) Pre-School Inventory in six classes. 3) Children's Embedded Figures Test. Initiation of the A-TESP in nine classrooms (staggered).
Spring 1976	Lessons 9 - 16	Post-Instructional Interview #1. Midyear Progress Report Post-Instructional Interview #2.
Summer 1976	Lessons 17 - 24	Post Instructional Interview #3 Piagetian Tasks M-Space Stanford Achievement Tests A-TESP Achievement Tests. Final Report Teacher Questionnaires 1) A-TESP Evaluation 2) Student Personality Evaluation.

Table 4. Correlations Between Other Measures of Individual Differences.

Correlation Matrix of a few selected scores collected in this study to measure individual differences.

1 Metropolitan: Total Battery	2 Preschool Inventory: Total Battery	3 Stanford Achievement: Total Battery	4 A-TESP Achievement: Total Battery	5 Conservation: Matter	6 M. Space: B.D.S.	7 CEFT: Total Battery	
	$r = 0.4243$ $p \leq 0.001$ $r^2 = 0.18$	0.8412 0.001 0.71	0.4499 0.001 0.20	0.2849 0.005 0.08	0.3637 0.001 0.13	0.3838 0.001 0.15	1
		0.5577 0.001 0.31	0.2684 0.003 0.07	0.2779 0.002 0.08	0.4824 0.001 0.23	0.2752 0.002 0.08	2
			0.6718 0.001 0.45	0.5514 0.001 0.30	0.6281 0.001 0.40	0.5718 0.001 0.33	3
				0.1954 0.023 0.04	0.3218 0.001 0.10	0.2564 0.004 0.07	4
					0.2817 0.002 0.08	0.3398 0.001 0.12	5
						0.2066 0.016 0.04	6
							7



The Modified Piagetian Clinical Interview (MPCI) Format.

Figure 6. The MPCI Format

Figure 7a. Example of the MPCI Situation.

Figure 7b. Example of MPCI Situation.

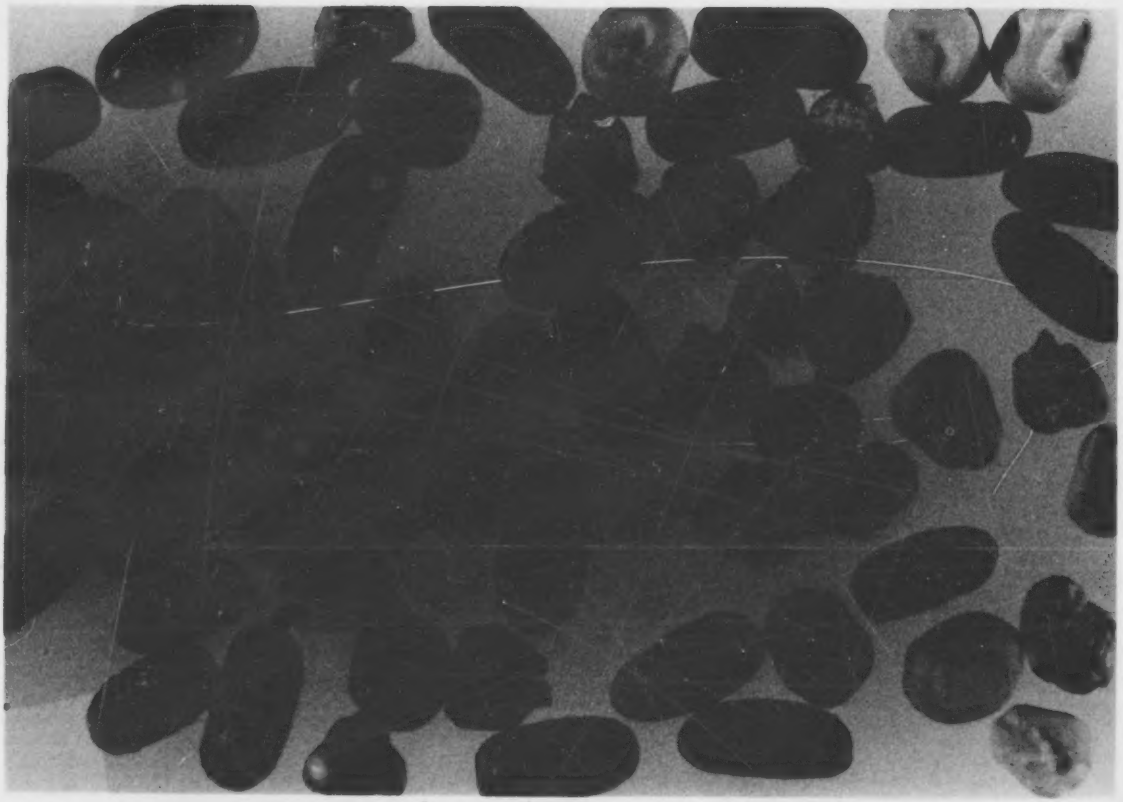


Figure 8a. . Exemplar Used to Initiate Interviews.

Figure 8b. Exemplar Used to Initiate Interviews.

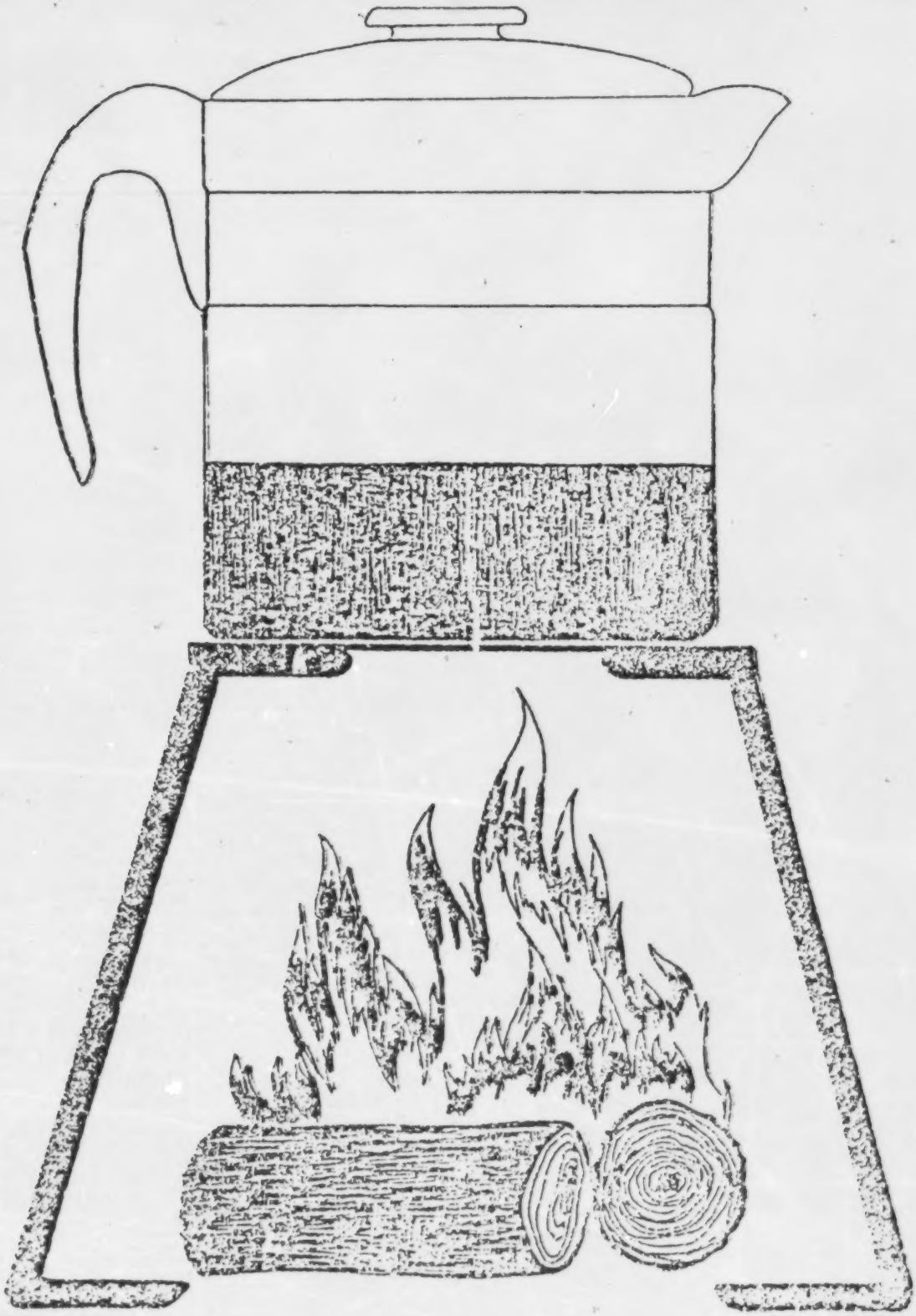


Figure 8c. Exemplar Used to Initiate Interviews.

Figure 9a. Task Using Battery and Lightbulb Exemplars.

Figure 9b. Task Using Battery and Lightbulb Exemplars.

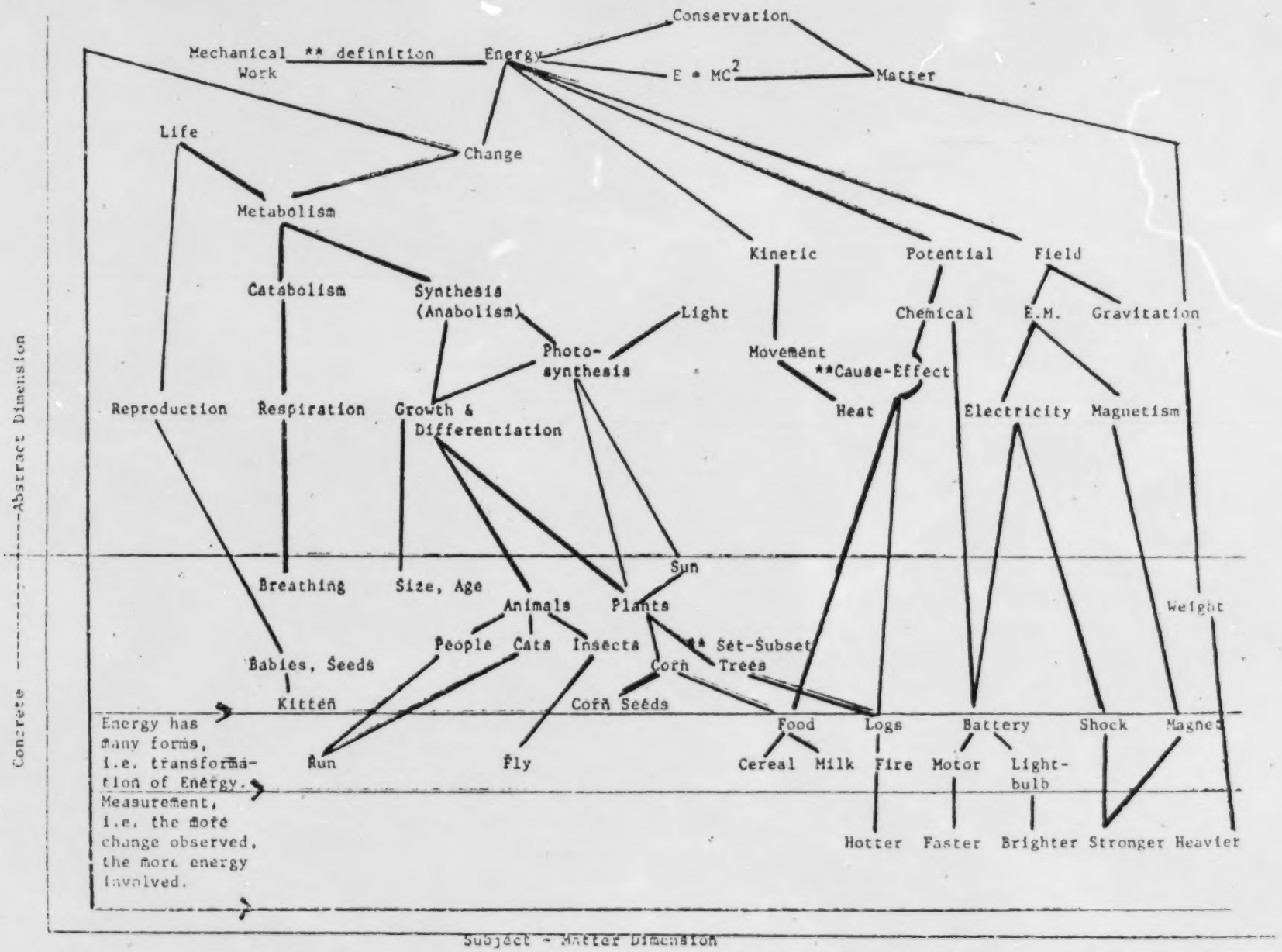


Figure 10. Concept Map Concerning the Concepts of "Life" and "Energy".

Table 5. Transformation of Interview Data.

Sequence of the Transformation of Interview Data Into Propositional Form

Recording

↓

Transcript

Q: What does alive mean?
A: Well it means that you grow.
Q: And what does grow mean?
A: Grow means that you can move; like the wind blows and helps the corn to move. Wind does it, and people do it all the time.
Q: Is the wind alive?
A: Yes.

↓

Transformation Into Independent Interviewee Discourse

Alive means that you grow.
Grow means that you can move; like the wind blows and helps the corn to move. Wind does it (moves) and people do it all the time.
Wind is alive.

↓

Transformation to Propositional Format

↙ ↘

or

1) Alive means that you grow.
2) Grow means that you can move; like the wind blows and helps the corn to move.
3) Wind does it (moves) and people do it all the time.
4) Wind is alive.

1) Alive means that you grow.
2) Grow means that you move.
3) Wind blows and helps the corn to move.
4) Wind does it (moves) all the time.
5) People do it (move) all the time.
6) Wind is alive.

Pre-Instructional Interview (no more than one minute)

CHILD #31 Q
Class #2
Pre of Rel Propositions

Post-Instructional Interview (no more than one minute)

Table 6. All Propositions Compiled for Case Study 2.

Table 7. Comparison of Children in Case Studies 1 and 2.

Comparison of the children in Case Studies 1 and 2.

Variable	Subject #27 (Case Study 1)	Subject #31 (Case Study 2)
Sex	female	female
Date of Birth	8/69	7/69
Metropolitan	79	83
PreSchool Inventory	58	61
Stanford Achievement		
1) Word Study Skills	82	86
2) Mathematical Concepts	88	72
3) Math Comprehension and Application	99	99
4) Listening	80	94
Children's Embedded Figures Test (CEFT)	16	9
BDS	E + 1	E + 1
Conservation Matter, Length, Number	- + +	- + +[a]
# Association Piles	4	4
Constitution of Piles	123/456/78/9	45/36/1789/2[b]
Explanation of Piles	Energy Life	Life Food Air Energy

a. (-) means non-conservation; (+) means conversation.
b. As in all other non-verbal tasks (drawing, sorting, etc.), association piles have little meaning without the subject's terpretation (cf. section III-4, especially pp. 93-94).

Table 8. Comparison of Pre - Post Data for Case Study 1.

Case Study 1- Are Seeds Alive? How Can We Check? The Continuity of Life - A Sophisticated Response.

Example 3 (From Case Study 1)

Pre II

3. Real seeds are alive because you can squeeze real seeds but you can't squeeze phoney ones.

4. Alive means that things are squeezeable.

5. Alive doesn't mean anything else.

6. Like if these seeds were alive you could squeeze them.

Post II

32. These are seeds, they're alive.

5. I don't know if *these* seeds are alive.

6. I think they're (seeds are) dead.

7. They (seeds) won't grow alone.

8. There is nothing you can do to make them (seeds) grow because they might be dead and if they're dead they won't grow.

9. To check if they're (seeds are) alive, you have to wait for a few days and if there's water, light, and air they might grow into big plants.

10. If they (seeds) grow, they're alive.

Table 9. Comparison of Pre - Post Data from Case Study 2.

Case Study 2 - Are Seeds Alive? How Can We Check? The Continuity of Life - A Misconception.

Example 6 (From Case Study 2)

Pre II	Post II
7. Seeds aren't alive	11. These seeds aren't alive; it doesn't look like they're alive
8. When you plant seeds they grow	15. Plants outside are alive but not them (seeds) , they're just seeds
	24. These aren't alive because they're seeds
	12. I could tell if they were alive because they'd be growing.
	16. If you planted seeds and gave them water and sun and air, they would grow
	26. The seeds aren't alive now but they could be (alive) if they had water and sun and air

Table 10. Case Study 2 - Criteria for "life".

Case Study 2 - Criteria for "Life". (Selected Propositions From Table

Pre II	Post II
3. Alive means that they move	13. Alive means you can move around by yourself and stuff and you can talk
	17. If something is alive it moves
	33. If something is alive it means that it moves or it grows cause kids grow
	31. Those flies aren't alive because they're not moving
	21. Flour can't be alive because flour can't do anything
	32. This light is alive because if you put a battery it would shine up

Table 11. Examples of Lesson Content From A-TESP Level I Lessons #13 and #14.

Lesson Content - "Identical" A-T Instruction Leading to Differential Learning Outcomes.

Example 7 (From the A-TESP lesson)

A. Lesson 13, p. 9:

"How will you know if a seed is alive?

When you see a seed start to grow, you will know the seed is alive."

B. Lesson 14, pp. 2 - 4:

"You must watch the seeds that you planted and see if they grow ... This corn seed is alive because it's growing ..."

"... because this bean seed in the next movie is growing, we know it is alive."

Table 12. Example From Case Study 4.

Case Study 4 - Are Seeds Alive? How Can We Check? The Continuity of Life

Example 8 (From Case Study 4)

Pre II	Post II
1. These are peas	2. Plants will grow if you put the seed in water or sun
3. The peas are dead because they're water	6. The seeds aren't alive yet
4. If you put them (peas) in the ground they would turn into a pea plant	7. The seeds could be alive if the sun and water helped them
5. The pea plant would be alive	

Table 13. Example From-Case Study 5.

Case Study 5 - Are Seeds Alive? How Can We Check? The Continuity of Life

Pre II	Post II
1. They're seeds	1. Those are seeds
3. The seeds are not alive	2. They're all dried up
5. You can plant the seeds	3. You can plant the seeds
9. The seeds grow into a plant	14. The seeds are not alive because they don't have water
13. The plant is alive	15. If they get water, they'll grow
	16. When they grow they're alive
	17. When seeds get water, they will be alive

Table 14. Example From Case Study 3.

Case Study 3 - Are Seeds Alive? How Can We Check? The Continuity of Life

Pre II	Post II
Control - No Pre II administered.	1. Those are beans; they grow
	2. They (beans) need light and water and soil
	22. The corn seeds aren't alive
	11. All of these seeds would grow because they're real beans
	6. The beans are not alive because you can't see any roots or anything
	8. If they have roots and a stem then they're alive and if not then they're not alive
	9. If you took this one bean and gave it water and sun and light it would grow and it would then be alive
	10. The bean is not alive now but it can be alive
	23. All of the seeds. They're alive if they grow and they're not alive right now

Table 15. Example From Case Study 1.

Case Study 1 - The Making of "Energy"; A Misconception

Pre II

68....it makes more electricity so you can see more light

70. It's just a big log chopped down

71. People make fire...

72. This is a picture of a coffee pot

73. There is no energy in this picture

Post II

57. The battery and the wood are the same because they make energy

58. The fire makes energy

59. The fire makes energy; the wood doesn't

66. The sun makes energy but it can't move around

Table 16. Example From Case Study 1.

Case Study 1 - The Transformation of Energy: A Misconception.

Example 25 (From Case Study 1)

Pre II

77. The sun hasn't got one bit of energy

PostII

69. The corn gets energy from the water

70. The corn plant gets its energy from the water

75. The sun has nothing to do with the other pictures (i.e. the picture series)

Table 17. Example From Case Study 1.

Case Study 1 - Fire as an Energy Transformation: A Misconception.

Example 27 (From Case Study 1)

Pre II	Post II
70. It's just a big log chopped down	52. The coffee is getting hot because there's fire in there
71. People make fire...	53. If you stick your head in a fire, it will burn up because fire is hot
72. This is a picture of a coffee pot	54. Hot means it's real hot
73. There is no energy in this picture	55. The fire is coming from the wood
	56. You rub a match against some sandpaper and it gets lit so you put it on wood and it burns real big like this fire
	57. The battery and the wood are the same because they have energy
	58. The fire makes energy
	59. The fire makes energy; the wood doesn't
	60. If you put another piece of wood on the fire it would get up to here and burn the coffee pot because more wood helps fires get bigger because wood helps fires grow because fire eats wood like termites

Table 18. Pre - Post Comparison From Case Study 2.

Case Study 2 - Explaining the Effect of Batteries Using a Conceptual Explanation

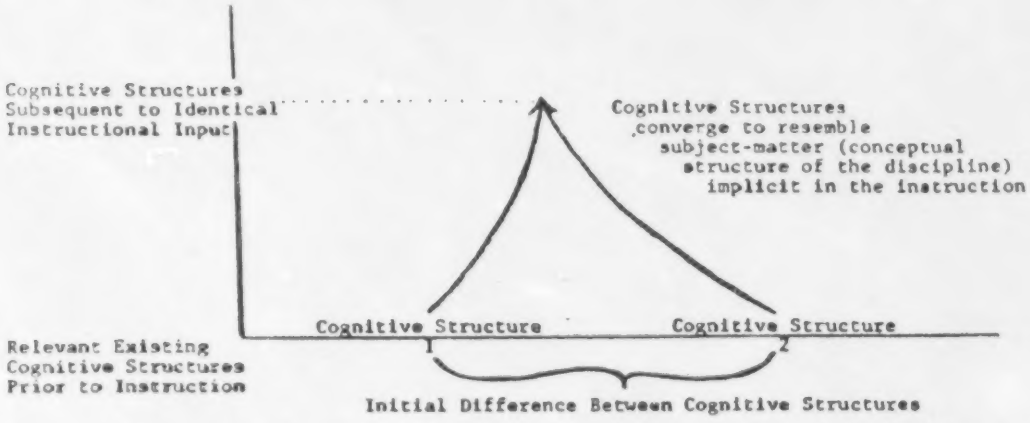
Pre II	Post II
26. Batteries have electric which makes them work	47. A battery can make things work because it has energy
27. Electric can make you die	48. The energy is inside the battery
28. Hot wires can make you die and some wires can't make you die	51. The light is going on because energy inside the battery comes up and into thelight and makes it come on
29. Electric can help you	54. The energy goes down in the machine and makes the little flag go around
35. The light is going on because there is electric in the battery	56. If you just touched the wires together without the battery the motor wouldn't go because the wires don't have energy

Table 19. Example From Case Study 2.

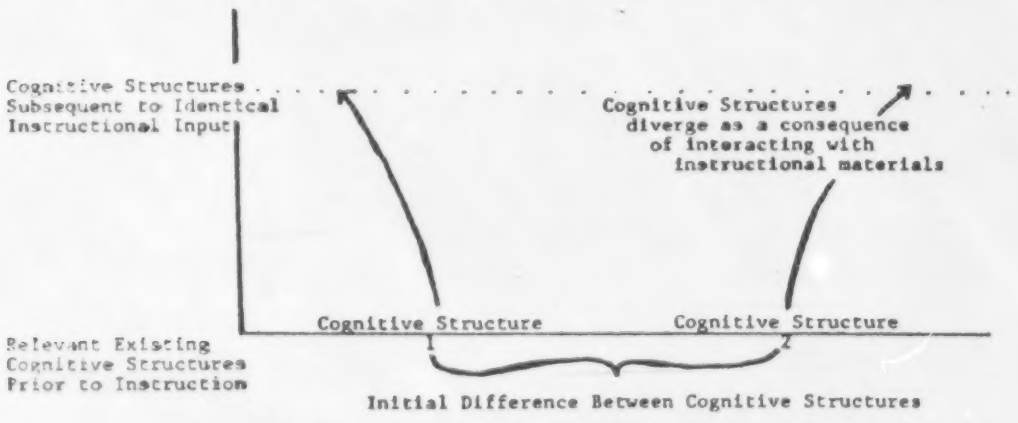
Case Study 2 - Fire and Energy: An Example of Concept Learning.

Pre II	Post II
29. Electric can help you	49. Energy helps you move
30. Electric can help you cook	52. The light is energy
34. The fire and the electric are the same because they can both cook stuff	58. The fire has hot grains in it and makes energy so it will get hot
	59. The fire doesn't make energy
	60. The heat is coming from the fire; from the stove
	61. If you chucked another log in there it would be a bigger flame because the logs have energy so the fire burns and it (fire) would be bigger

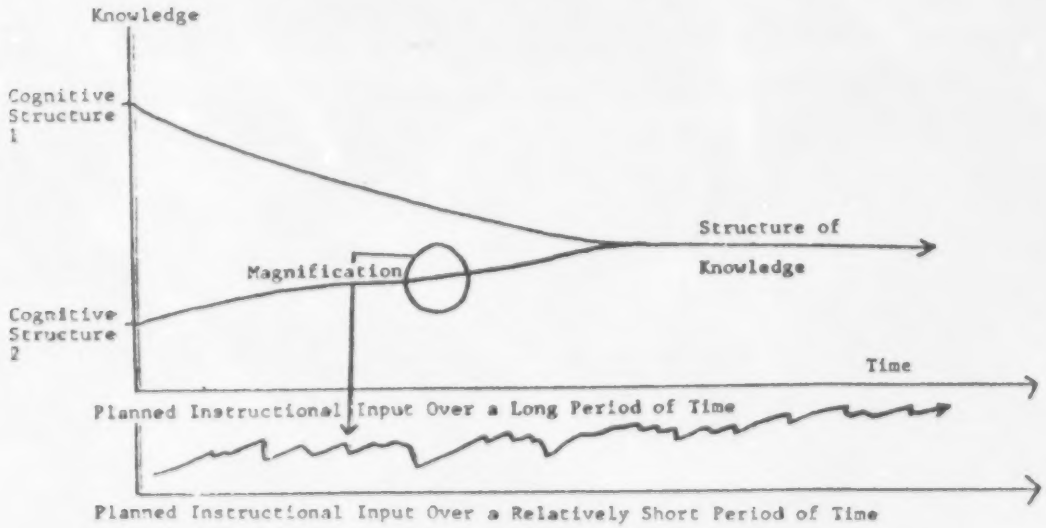
Figure 11. Convergence and Divergence of Cognitive Structures.



a. The Convergence of Cognitive Structures Due to a Controlled Input



b. The Divergence of Cognitive Structures Due to a Controlled Input



c. The Convergence of Cognitive Structures Due to Planned Instruction Over a Long Period of Time, And The Magnification of One Short Time Period

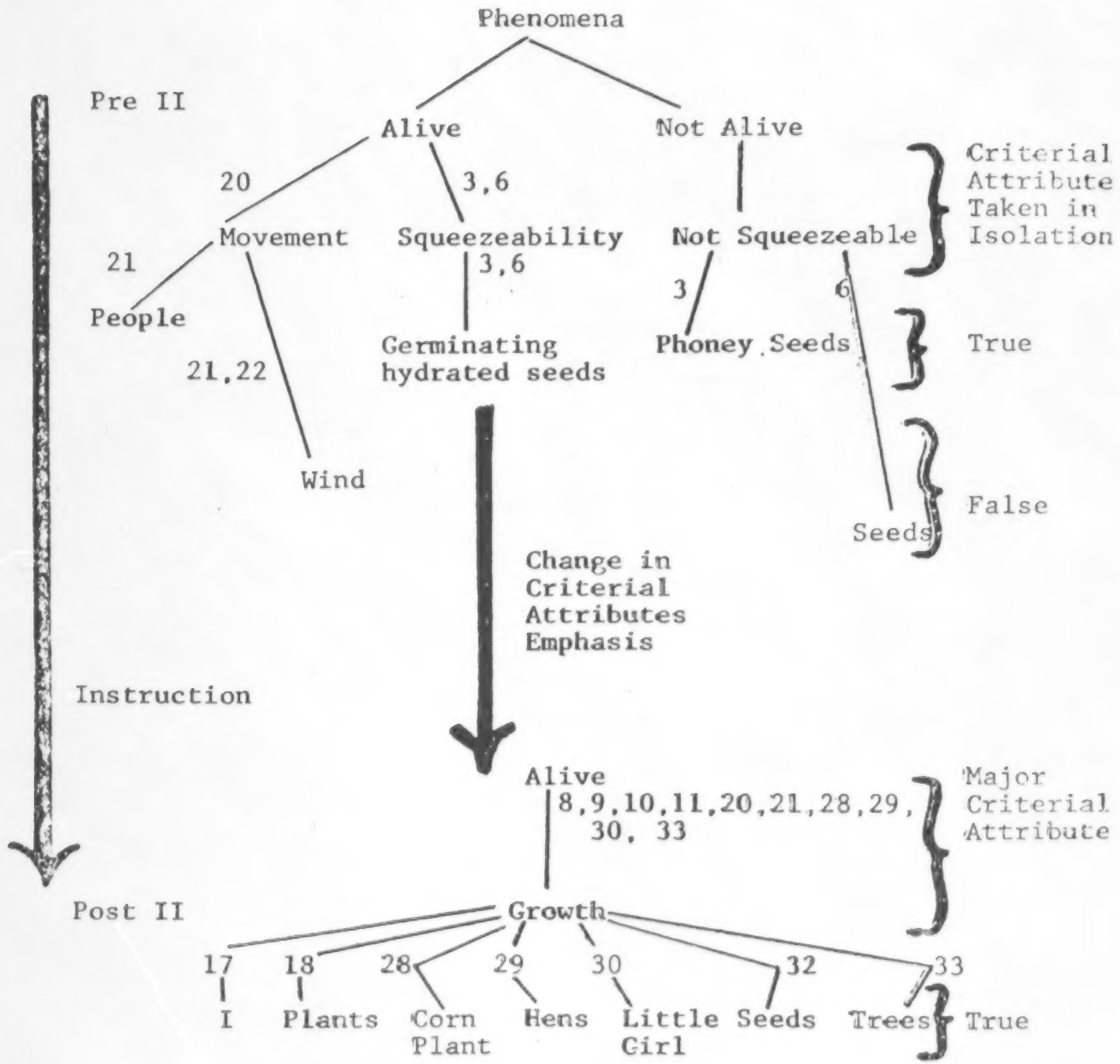


Figure 12. Learning Observed as a Shift in Emphasis of Criterial Attributes.

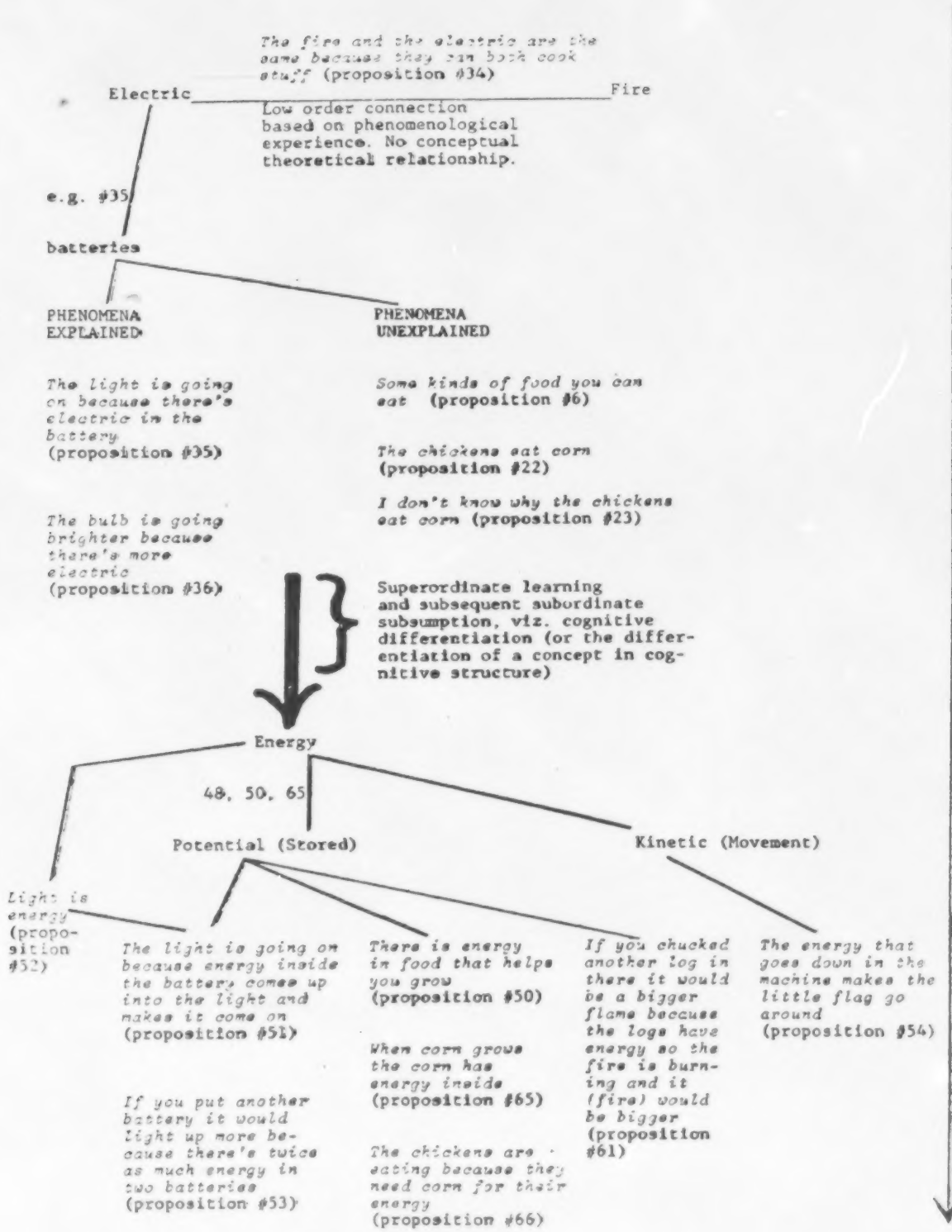

The fire and the electric are the same because they can both cook stuff (proposition #34)
Electric
Fire
Low order connection based on phenomenological experience. No conceptual theoretical relationship.
e.g. #35
batteries
PHENOMENA EXPLAINED
PHENOMENA UNEXPLAINED
The light is going on because there's electric in the battery (proposition #35)
Some kinds of food you can eat (proposition #6)
The chickens eat corn (proposition #22)
I don't know why the chickens eat corn (proposition #23)
The bulb is going brighter because there's more electric (proposition #36)
Superordinate learning and subsequent subordinate subsumption, viz. cognitive differentiation (or the differentiation of a concept in cognitive structure)
Energy
48, 50, 65
Potential (Stored)
Kinetic (Movement)
Light is energy (proposition #52)
The light is going on because energy inside the battery comes up into the light and makes it come on (proposition #51)
If you put another battery it would light up more because there's twice as much energy in two batteries (proposition #53)
There is energy in food that helps you grow (proposition #50)
When corn grows the corn has energy inside (proposition #65)
The chickens are eating because they need corn for their energy (proposition #66)
If you chucked another log in there it would be a bigger flame because the logs have energy so the fire is burning and it (fire) would be bigger (proposition #61)
The energy that goes down in the machine makes the little flag go around (proposition #54)
Observable change in the extension of the concept

Figure 13. Learning Observed as a Change in the Extension of a Concept.